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16. ABSTRACT
Synopsis

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(1) California Impact Test (216-F)
(2) Experimental California Soil Moisture-Density (M-D) Test

The comparative data compiled from the above mentioned tests was obtained from over forty going contracts in nine districts. The type of material tested ranged from clays to sands, and all tests were performed under field conditions.

The California Standard Sand Volume Test (Calif. 216-F) was used to determine the inplace density.

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STATE OF CALIFORNIA
HIGHWAY TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

AN EVALUATION OF THE EXPERIMENTAL CALIFORNIA SOIL COMPACTION TEST APPARATUS

66-22

MAY 1966

State of California
Department of Public Works
Division of Highways
Materials and Research Department

May 1966

Project Work Order
#425278 (23527-R)

Mr. J. C. Womack
State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is:

REPORT

ON

AN EVALUATION OF THE

EXPERIMENTAL CALIFORNIA SOIL

COMPACTION TEST APPARATUS

Study made by	Pavement & Foundation Sections
Under general direction of	E. Zube T. Smith
Project Supervisor	J. Cechetini
Report prepared by	J. Cechetini

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

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SYNOPSIS

This report presents comparative data on maximum test density, the optimum moisture content needed for maximum density, and relative compaction using two specific test methods. The two test methods are:

(1) California Impact Test (216-F)
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The comparative data compiled from the above mentioned tests was obtained from over forty going contracts in nine districts. The type of material tested ranged from clays to sands, and all tests were performed under field conditions.

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INTRODUCTION

If one were to ask a group of resident engineers to name a specification which is the most difficult to enforce, probably the answer would be obtaining and also maintaining the required relative compaction of an embankment constructed from silty or clayey material.

In a few districts where sand is readily available, contractors do not have a problem in obtaining and maintaining 90 to 100% relative compaction using minimum compactive effort. However, in other districts where most of the embankments are constructed from silts and clayey materials, contractors have found it difficult to meet the required relative compaction when using the California Impact Test results for the maximum test density.

This difficulty of obtaining the required relative compaction for silts and clayey soils, and the ease of meeting the required relative compaction for sands, has not only been a perplexing problem to the contractor but has also been the subject of a great deal of research by engineers from the Materials and Research laboratory.

The first attempt to correct this problem began with changing the test procedure of the California Impact Test. This included increasing the number of layers from 5 to 10 when a soil sample had a sand equivalent equal to, or greater than 25. By setting a sand equivalent limit, only the sandy soils would be affected by the additional layers. It was believed increasing the number of layers would increase the compactive effort, and in turn would increase the density of sandy soils. This procedure was discontinued after the problem was found to be more complex than was originally considered.

A variety of procedures were tried using different mold shapes, the thought being that possibly side wall friction caused the low densities in sandy soils. None of the various shaped molds or procedure changes resulted in any appreciable increase in densities for sandy soils.

In December 1961, a flexible wall compaction mold was designed and built (Figure 1) using the same principle as found in the Stabilometer. Results from soil samples compacted in this flexible wall apparatus were as follows:

(1) The weight per cubic foot for clayey soils was reduced approximately 10 pounds.

(2) The weight per cubic foot for sandy soils was approximately the same as results determined by the California Impact Test.

The objectionable features of the first flexible wall model were:

(1) The size of the soil sample was too small (1/35 cu. ft.)

(2) Difficulty in removing metal retaining sleeve after compacting the first lift, and when removing the sleeve the sample would be disturbed, causing an error when calculating the density.

(3) Extremely difficult to remove the samples from apparatus.

To alleviate these objectionable features, a second model similar to the one shown in Figure 2A and 2B was built in which a flexible tube (oil filled rubber tube 2" diameter) was placed in the center of the metal mold (6" diameter). This arrangement permitted the soil specimen to be compacted around the oil filled tube. Initial results from the second experimental compactor were encouraging. Results indicated that the density for sands was increased approximately 3 pcf. and the density for clays was reduced approximately 8 pcf.

An extensive evaluation study of the second experimental model required a two phase study which included:

(1) Laboratory investigational study.

(2) Field investigational study.

Data from both phases will be presented.

CONCLUSION

From the data presented by this study, it is concluded that:

(1) The maximum test density for sands as determined by the Experimental Impact Test is usually higher than the results obtained by the Standard California Impact Test; the range being from -3 to +8 pcf. and the average being +4 pcf.

(2) The maximum test density for clays, as determined by the Experimental Impact Test (M-D), is lower than the results obtained by the California Impact Test; the range being -4 to -18 pcf. with an average of -12 pcf.

(3) A statistical study made on all types of clays, (approximately 90 samples), shows when using the California Impact Test results for the maximum test density, 47% of the samples tested failed to meet the required 90% relative compaction. However, when using the Experimental Impact Test results for maximum test density, only 14% of the samples from the same locations failed to meet the same requirements.

(4) When comparing the two test methods on 40 contracts, in nine different districts, the results show that for all types of soils, (approximately 100 samples), 41% of the locations tested failed to meet the required relative compaction of 90% when using the California Impact Test results for the maximum test density. 5% of the locations tested failed to meet the same requirements when using the Experimental Impact Test results for maximum test density.

(5) Results show that contractors, during compaction usually increase the moisture content for clayey soils by approximately 7.0% above which is recommended by the California Impact Test.

(6) The average optimum moisture content for clays, as determined by the Experimental Impact Test is approximately 8.0% higher than results by the California Impact Test.

(7) It may be, our compaction requirements for expansive clays, when using the California Impact Test for maximum test density, are much too stringent, particularly when such demanding requirements may not be necessary. On the basis of studies by Dawson (1), Seed and Chan (2), and Singh (3), it seems that the swelling potential of clays can be reduced and the strength can be increased when compacted moderately and on the wet side of optimum.

LABORATORY STUDIES FOR EVALUATING THE EXPERIMENTAL IMPACT APPARATUS

The objectives of the first phase of this study were:

(1) Develop a workable test procedure.

(2) To determine the reproducibility using several technicians to perform compaction tests on various types of soils.

(3) To test as many soils as possible from the various districts by both the standard and experimental test methods.

1. Procedure.

The first series of samples were compacted in three layers with the thickness of each layer being approximately 1.33 inches. The weight, drop of the hammer, and the number of blows per layer, and leveling off blows remained the same as used by the California Impact Test procedure, i.e.,

(a) A 10 lb. hammer, falling 18"

(b) 20 blows per layer

(c) 5 blows for leveling off load.

When compacting the first two layers, a metal collar is used to restrain the top portion of the oil filled tube from bulging. This collar, however, is removed when compacting the third and final layer. When compacting the first two of the three layers, it was practically impossible to place the metal restraining collar at the proper height on the oil filled rubber tube. By modifying the number of layers from three to two, and increasing the total height of test specimens from 4.00 to 4.25 inches, the problem of the restraining collar was virtually eliminated.

When removing clayey samples from the new apparatus, it was noted there were an excessive amount of voids, usually under the larger aggregates. It was found by rodding each of the two layers with a 3/8" rod for 20 blows prior to compaction, the amount of voids were decreased.

The density results using the two-layer procedure were:

(a) The density for sands was increased approximately 3 pcf. more than density obtained by the California Impact Test.

(b) The density for clays and silts was approximately 8 pcf. less than the results determined by the California Impact Test.

The results obtained by the two-layer procedure were in line with the results we had hoped for in clays, silts and sands.

2. Reproducibility

After the two-layer procedure had been adopted, soil samples were quartered and sealed in cans. One technician compacted two soil samples with identical moisture content. After completion, the second technician compacted the two remaining specimens from the quartered soil sample using the same moisture content as used by the first technician. Various types of soil samples were treated in this manner.

The results showed there was approximately 2 pcf. variation when all material passed the #4 sieve. However, for all the samples tested, (including samples with 3/4" aggregates), the average variation was approximately 3 pcf. The probable cause for better reproducibility when removing the plus #4 material is due to the orientation and/or slight degradation of larger aggregates.

Results indicate that if soil samples contain plus #4 materials, one can expect to have an average variation of 3 pcf. when using the Experimental California Soil (Moisture-Density) Apparatus.

3. Laboratory and Field Comparison Study

A. Laboratory Study.

During the early part of 1962 soil samples were requested and received from various districts to determine the density by both test methods:

(a) California Impact Test

(b) Experimental California Soil Moisture-Density (M-D) Apparatus.

The dry density results determined by the Experimental Impact Test were as expected, with sands being approximately 3 pcf. heavier, and clays from 5 to 12 pcf. lighter when compared with results obtained by the California Impact Test.

B. Field Study

In the summer of 1962, we were permitted to integrate our field study with a crew from the Foundation Section, who were conducting correlation studies on going contracts in Districts 03 and 10, comparing inplace densities by different methods, namely:

(a) Nuclear Test.

(b) Sand Volume Test.

The inplace moisture content was determined by:

(a) Nuclear Test.

(b) Oven Dry Test.

Approximately seven inplace density measurements were made at each location. The distance between each inplace density was approximately 2 feet. At one of the Sand Volume test holes, a large sample was obtained, thoroughly mixed and then quartered. The samples were tested as follows:

(1) The district field laboratory crew determined the optimum moisture and density by the California Impact Test.

(2) The headquarters laboratory crew determined the optimum moisture and density by the Experimental California Soil Moisture-Density Apparatus under field conditions.

(3) Samples were sent to headquarters laboratory for testing which included optimum moisture and maximum density results determined by the California Impact Test and by the Experimental Impact Test.

Each of the ten contracts selected in the two districts were tested approximately every two weeks for a period of about three months.

FIELD RESULTS FROM DISTRICT 03 AND 10

The results of this study are presentec in the attached tables.

Table 1-A

Column 1 = Materials and Research test numbers.
2, 3, 4, 5, 6, 10, 11 = Tests which were completed in headquarters laboratory.
7, 9 = Results from California Impact Test. Tests were performed in the field by district field laboratory crew.
8 = Density (Dry) determined by the Experimental California Soil M-D Apparatus.
12, 13 = Results determined by headquarters crew.
14 = Relative compaction results when using California Impact Test, (Column 7) as the maximum test density.
15 = Relative compaction results when using Experimental Impact Test, (Column 8), as the maximum test density.

The Experimental Impact Test results were about 6 pcf. less and required about 5% more moisture than the results obtained from the California Impact Test. When using the California Impact Test for the maximum test density, 75% of the locations tested failed to meet the required relative compaction, while 62% failed when using the Experimental Impact Test for the maximum test density.

Table 1-B
The Experimental Impact Test density results were about 4 pcf. less, and the optimum moisture content averaged about 8% more than the results determined by the California Impact Test. On this particular contract, a considerable difference in weight per cubic foot is noted between the field and headquarters laboratory California Impact Test results. (Column 7 vs. 10).

When using the California Impact Test for the maximum test density, 65% of the location tested failed to meet the required relative compaction, while 41% failed when using the Experimental Impact Test for the maximum test density.

Table 1-C

The difference between the two impact tests averages about 3 pcf., with the Experimental Impact Test being the lighter of the two. The optimum moisture content for the two tests is about the same.

As is shown, the California Impact Test failed 30% of the locations for not having the required relative compaction, while the Experimental Impact Test failed 10%.

Table 1-D

The difference between the two impact test results was about 3 pcf., with the Experimental Impact Test results being lighter. The optimum moisture content determined by both tests was approximately the same.

When using the results from the California Impact Test for the maximum test density, 25% of the locations tested failed to meet the required relative compaction, while 20% failed when the Experimental Impact Test results were used for the maximum test density.

Table II - A, B, C, and D

These tables show the results of tests which have been compiled from four going contracts with District 10. Data shows that the Experimental Impact Test results range from 1 to 6 pcf. less than the California Impact Test results.

The average for the four contracts in District 10 which failed to meet the required relative compaction when using the California Impact Test results for the maximum test density is 54%. When using the Experimental Impact Test results for the maximum test density 33% failed.

It is noted that approximately the same percentage of locations were failed by both impact tests in District 03, as shown in Tables 1-A; 1-B; 1-C; 1-D.

FIELD RESULTS FROM VARIOUS DISTRICTS

Figures 3 through 8 are the plotted results from going contracts in nine districts. Not included in this report are the results from impact tests which were performed in the laboratory. The reason for omitting laboratory test data from this report was to compare the two impact test results under actual field conditions, thereby limiting the variables that may occur when attempting to compare field versus lab data.

Figure 3 represents the variation in weight per cubic foot determined by the Experimental California Soil M-D Apparatus for various types of soils. This variation is compared with the results of the California Impact Test represented by the "0" line. Figure 3 shows that the average density for sands and sandy silts are increased by the Experimental Impact Test from -3 to +8 pcf with the average being +4 pcf.

The probable causes for the difference in density for sands when comparing the two impact test methods are:

(a) The Experimental Impact Apparatus with its larger mold (6" diameter), and oil filled center tube, allows the sand particles freedom of movement during compaction. This movement or reorientation of the sand particles aids the sample in being compacted into the smallest possible volume.

(b) The small diameter (2-7/8"), and the solid metal mold makes freedom of movement for sand particles practically impossible in the California Impact Test. Without proper orientation of the sand particles maximum density would be difficult to obtain.

As shown, the Experimental Impact Test density results are usually higher for sandy soils than those obtained by the California Impact Test. However, the compactive effect by the Experimental Impact Apparatus (10,300 Ft/lb per cubic foot) is considerably less than that of the California Impact Test (40,000 Ft/lb per cubic foot).

Also shown in Figure 3 are the variations in densities for clayey soils as determined by both methods. The decrease in density for clays range from -4 to -18 pcf with -12 pcf being average. It is believed that the primary reason for this difference in densities is excessive degradation of the large particles in the clayey soils by the California Impact Test. This is illustrated by the following example: On a contract in District 03 a haul road was in constant use for several hours by heavy equipment (D.W. - 641's, 95 tons). The soil was classified as a clay and approximately 10% of the material was oversize (+3/4"). This haul road had failed to meet the required 90% relative compaction when using the California Impact Test results for the maximum test density. However, using the results from the Experimental Impact Test for the test density, the relative compaction was 95%. The compacted soil cores from both impact tests were examined after the densities were determined and it was found that:

(a) The material from the cores compacted in the California Impact Test showed all material passed the 1/2" sieve, and only a small percentage was retained on the #4 sieve. The absence of larger size aggregates indicated excessive degradation.

(b) The compacted soil cores from the Experimental Impact Apparatus showed that most of the larger aggregates were not broken during compaction. It is obvious that the heavy construction equipment did not degrade the soil.

Figure 4 represents the distribution of dry densities between the Experimental and California Impact Test results for various types of soils. The California Impact Test results are represented by "O" located on the axis of the abscissa.

Figure 5 represents the maximum density for all the soils tested in the various districts by both impact test methods. As shown, there is a definite limit where the density results by the Experimental Impact Test show an increase over the California Impact Test results. This limit ranges from 120 to 130 pcf. and most sandy soils are in this range. Above 130 pcf. are the gravels and both impact test results are about the same. In the density range from 70 to 110 pcf., the two impact test results become widely separated, and this is the density range for most silt and clayey soils.

It may be well to point out that in his paper, R. F. Dawson (1) recommends that the expansive clays be compacted to some minimum density rather than to a maximum. The reason being the less dense materials might permit underlying clays to swell, and thus reduce swelling pressure.

Figure 6 is a comparative study of optimum moisture content determined by the two impact tests.

The optimum moisture content for clays determined by the Experimental Impact Test is about 8.0% higher than required by the California Impact Test. For sandy clays, the difference in optimum moisture contents between the two impact tests is about 3.0% with the Experimental Impact Test requiring the higher percentage of the two tests. For sands, both tests require approximately the same percentage of water for optimum moisture.

H. B. Seed, and C. K. Chan (2) show that clays compacted on the dry side of optimum exhibit higher swelling characteristics and swell to a higher water content than do samples of the same density compacted on the wet side of optimum.

Based on the studies by Dawson (1), Seed and Chan (2), it appears that the swelling potential of the expansive clays can be reduced by moderate compaction on the wet side of optimum.

H. A Singh (3) suggests that expansive clays compacted moderately and wet of optimum may be stronger than soils compacted under other conditions.

Figure 7. In this figure the inplace moisture content from going contracts is compared with optimum moisture content determined by the Experimental Impact Test.

As shown on the distribution curve for clays, the average moisture content is approximately the same. The average inplace moisture content for sandy clays is about 5% less than the average optimum moisture content obtained by the Experimental Impact Test.

Figure 8 represents inplace moisture content versus the optimum moisture content by the California Impact Test. The distribution curve for clays shows the average optimum moisture content determined by the California Impact Test is approximately 7.0% less than average inplace moisture content.

Figure 9 represents a comparison of relative compaction results determined by the California Impact Test and by the Experimental California Soil M-D Apparatus. It is shown that 41% of all the locations tested in nine districts failed to meet the required relative compaction when the California Impact Test results were used for maximum test density. However, when using the Experimental Impact Test results for maximum test density, 5% failed to meet the same relative compaction requirements.

STATISTICAL STUDY

After completion of our outlined compaction study, we made a statistical analysis on data obtained from all clayey soils tested. As shown in Figure 10, of the 91 clayey soils tested, at that particular stage of construction, 47% fell below the 90% relative compaction limit when the California Impact Test results were used for maximum test density. When the results from the Experimental Impact Test were used for maximum test densities, only 14% of the clayey soils fell below the 90% relative compaction requirement.

This, however, does not indicate that 47% of the embankments represented did not meet the specifications. The results of this study were not obtained using random sampling procedures and the number of observations varied from project to project, which no doubt biased the results. However, these figures do allow a direct comparison between the two testing methods.

SUMMARY

This research project has many promising features, and research is continuing with various types of compaction molds and procedures. Considerable research is also being done with nuclear equipment in this field. However, we are not as yet, to the point where a decision can be made on future compaction testing equipment or procedure.

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TABLE I - A

III-BUT-3C,CHC,D 63-3T13C4

	GRADING					FIELD RESULTS			Cal. Imp. Lab Results		Sand Vol.		R/C	
Test #	4 to 200	200 to 5 u	-5u	PI	SE	Dry Den Cal. Imp	Exp.* Dry. Den	Moist. %	Dry Den	Moist %	Dry Den	Moist. %	Field	Exp.
Column- 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	27	44	29	15	7	109	103	17.8	106.1	20	89	11.1	82	87
2						111	105	14.8			85	8.1	77	81
3						112	106	19.8			104	15.1	93	98
4						104	98	19.8			83	13.0	80	85
5						104	98	20.5			91	8.7	87	93
6						109	103	17.6			82	10.7	75	80
7						-	-	-			90	12.9	-	-
8	33	36	24	9	11	120	114	12.4	121.0	13.6	96	3.4	80	84
9						122	116	12.9			99	3.8	81	86
10						114	108	15.8			90	12.8	78	83
11						109	103	17.6			85	7.8	78	83
12						112	106	15.3			90	6.7	80	85
13	35	47	16	2	10	112	106	14.9	115.2	14.7	79	8.7	71	75
14	48	31	20	6	11	117	111	15.2	118.0	16.3	105	17.9	89	94
15						115	109	14.0			103	19.8	90	95
16						112	106	14.7			106	17.2	94	100
17						115	109	15.0			105	20.0	92	96

*Experimental California Soil Moisture Density Apparatus.

TABLE I - B

III-But-21-B,Orl (62-3T13C26)

	GRADING					FIELD RESULTS			Cal. Imp. Lab Results		Sand Vol.		R/C	
Test #	4 to 200	200 to 5 u	-5 u	PI	SE	Dry Den Cal. Imp	Exp.* Dry Den	Moist %	Dry Den.	Moist %	Dry Den	Moist %	Field	Exp.
Column- 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1						94	90	19.5			79	31.4	84	88
2						98	94	19.2			94	23.3	97	100
3	43	32	19	18	10	130	126	10.4	98	22.3	108	3.6	83	86
4						115	111	15.8			105	4.8	91	94
5						117	113	13.1			106	4.9	91	96
6	46	21	19	17	15	111	107	16.6	125	11.6	92	18.1	83	86
7						120	116	13.1			105	13.6	87	90
8						122	118	9.4			108	13.4	89	92
9						117	113	11.1			98	3.5	84	86
10	79	12	4	2	38	125	121	10.0	131	9.5	106	1.7	85	88
11						122	118	9.3			109	3.1	87	92
12						101	97	21.1			81	17.2	80	84
13						96	92	21.2			82	18.1	85	89
14						116	112	14.2			103	7.2	90	93
15						122	118	11.7			111	9.3	90	93
16						97	93	20.5			91	22.4	94	98
17						88	84	24.2			77	26.6	87	91

*Experimental California Soil Moisture Density Apparatus.

TABLE I - C

III-Gle-45-A,B (63-3T13C5-F)

	GRADING						FIELD RESULTS			Cal. Imp. Lab Results		Sand Vol.		R/C	
	Test #	4 to 200	200 to 5 u	-5 u	PI	SE	Dry Den. Cal. Imp	Exp.* Dry Den	Moist %	Dry Den	Moist %	Dry Den	Moist %	Field	Exp.
Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	1						141	138	5.4			135	6.4	96	98
	2											130	5.2		
	3						144	141	9.7			142	6.0	99	101
	4											152	6.2		
	5	51	6	1	NP	29				139	6.1	130	6.1	94	
	6														
	7						140	137	7.3			135	5.0	96	98
	8						137	134	7.0			135	6.7	98	100
	9						139	136	6.0			133	5.4	96	98
	10	35	37	25	7	8	122	119	11.0	130	9.3	108	5.7	88	91
	11						120	117	12.0			101	6.2	85	87
	12						123	120	10.0			108	4.4	88	90
	13											131	4.8		
	14						137	134	8.5			138	5.3	101	103
	15						119	116	12.0			106	9.9	90	92
	16														
	17														

*Experimental California Soil Moisture Density Apparatus.

TABLE I - D

III-ED-65-B (63-3T13C6)

	GRADING					FIELD RESULTS			Cal. Imp Lab Results		Sand Vol.		R/C	
Test #	4 to 200	200 to 5 u	-5 u	PI	SE	Dry Den. Cal. Imp	Exp.* Dry Den.	Moist %	Dry Den	Moist %	Dry Den.	Moist %	Field	Exp
Column 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	74	16	6	4	24	127	124	11.1	131.8	9.9	110	7.1	86	88
2						126	123	11.6			110	7.1	88	89
3						128	125	10.6			121	6.2	94	97
4						129	126	10.4			108	6.0	84	86
5						126	123	10.6			115	6.6	92	94
6						126	123	11.0			108	8.6	86	88
7						128	125	9.0			122	6.7	95	98
8	81	17	0	5	29	126	123	9.7	129.9	9.5	115	7.2	91	93
9											116			
10						128	125	10.4			117	5.9	92	94
11						128	125	11.7			116	6.8	90	93
12						130	127	10.3			122	5.6	94	96
13						125	122	11.3			114	8.7	92	93
14	58	25	15	5	19	125	122	12.0	130.3	10.2	104	9.1	83	85
15						125	122	12.1			120	7.4	96	98
16						128	125	11.6			122	7.0	96	98
17						124	121	11.6			114	7.1	92	94

*Experimental California Soil Moisture Density Apparatus.

TABLE I - D (contd)

III-ED-65-B (63-3T13C6)

	GRADING					FIELD RESULTS			Cal. Imp. Lab Results		Sand Vol.		R/C	
Test #	4 to 200	200 to 5 u	-5 u	PI	SE	Dry Den Cal. Imp	Exp.* Dry Den.	Moist %	Dry Den	Moist. %	Dry Den	Moist %	Field	Exp
Column 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
18						126	123	11.1			113	6.7	90	92
19						124	121	11.3			110	8.9	89	91
20						133	130	8.0			121	5.4	91	93
21						133	130	8.3			134	5.8	101	103
22	67	19	13	7	19	133	130	9.2	133.5	9.9	132	6.3	100	102
23						131	128	9.9			128	7.4	98	100
24						130	127	9.8			117	7.1	90	92

* Experimental California Soil Moisture Density Apparatus.

TABLE II - A

X-Sol-7-I (63-10T13C1-I)

	GRADING					FIELD RESULTS			Cal. Imp. Lab Results		Sand Vol.			R/C
Test #	4 to 200	200 to 5 u	-5 u	PI	SE	Dry Den Cal.Imp	Exp.* Dry Den	Moist %	Dry Den	Moist %	Dry Den	Moist %	Field	Exp.
Column 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1						111	106	13.1			92	16.0	83	87
2						117	112	12.4			85	16.6	73	76
3	35	23	17	10	13	129	124	8.7	130	9.9	146	4.0	113	118
4						111	106	15.0			92	4.6	83	87
5	17	46	29	14	5	112	107	14.4	116	13.5	82	5.9	73	77
6						106	101	19.6			78	8.8	74	77
7						107	102	17.5			92	8.9	86	90
8						114	109	12.6			97	4.8	86	89
9						119	114	13.0			102	7.3	86	90
10	29	48	33	12	3	111	106	10.0	116	14.5	96	8.5	87	91
11						111	106	17.4			96	8.7	87	90
12						112	107	15.4			106	8.9	94	99
13						114	109	14.0			100	7.5	89	92
14						112	107	13.4			91	6.1	82	86
15						111	106	14.5			100	6.0	90	95
16						111	106	13.6			100	6.2	90	93
17						111	105	14.6			101	6.9	91	96
18						111	105	14.8			97	6.7	88	93
19	10	44	44	16	2	111	105	14.6	110	13.6	101	6.4	92	97

*Experimental California Soil Moisture Density Apparatus.

TABLE II - B

X-Sol-7-C,VAC,D (62-10T13C11-I)

		GRADING					FIELD RESULTS			Cal. Imp. Lab Results		Sand Vo.		R/C	
	Test #	4 to 200	200 to 5 u	-5 u	PI	SE	Dry Den Cal. Imp	Exp.* Dry Den	Moist %	Dry Den	Moist %	Dry Den	Moist %	Field	Exp.
Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	1						115	109	16.2			100	14.0	86	91
	2	37	20	11	17	15	125	119	11.6	129.8	9.8	109	11.6	88	92
	3						117	111	12.4			100	12.4	85	90
	4						118	112	8.7			107	8.7	91	96
	5						123	117	10.6			109	6.2	88	93
	6						119	113	7.5			115	9.7	96	102
	7						114	108	12.8			108	6.4	95	100
	8	24	42	32	14	7	117	111	15.5	120.0	12.6	114	11.1	98	103
	9						118	112	7.8			112	7.8	95	100
	10						114	108	14.8			101	10.6	89	94
	11						116	110	9.1			98	11.4	84	89
	12						117	111	13.4			108	13.4	92	97
	13	42	37	11	8	11	111	105	14.4	119.1	14.4	98	14.4	88	93
	14						100	94	21.0			94	21.9	94	100
	15						103	97	15.3			97	17.9	94	100
	16						130	124	9.4			120	7.1	92	97
	17						106	100	17.7			95	17.7	90	95
	18						100	94	20.5			87	20.5	87	93
	19						110	104	17.5			85	19.9	77	82
	20						108	102	16.5			90	16.5	84	89
	21						107	101	17.1			95	17.1	89	94
	22						109	103	14.7			94	14.7	86	91

*Experimental California Soil Moisture Density Apparatus.

TABLE II - C

X-SJ-4-C-Lod (62-10T13C14-F)

	GRADING					FIELD RESULTS			Cal. Imp. Lab Results		Sand Vol.		R/C	
Test #	4 to 200	200 to 5 u	-5 u	PI	SE	Dry Den Cal. Imp	Exp.* Dry Den	Moist %	Dry Den	Moist %	Dry Den	Moist %	Field	Exp.
Column 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	75	18	6	NP	35	113	109	12.1	128	9.6	104	3.5	93	96
2						98	94	15.7			97	15.7	99	103
3						141	137	5.7			137	4.5	98	100
4						141	139	5.7			138	4.2	98	101
5	35	7	2	NP	35	141	137	5.7	140	7.3	140	4.4	100	102
6						141	135	5.7			137	4.4	97	100
7						129	125	8.1			109	8.7	85	87
8						130	126	8.0			122	4.3	94	97
9						130	126	8.1			117	6.8	90	93
10						130	126	9.9			100	4.1	78	80
11						133	129	8.4			110	5.5	83	86
12	73	17	9	2	21	132	128	8.4	132	9.4	106	3.6	81	83
13						133	129	7.5			100	2.7	75	77
14						130	126	8.4			108	7.1	84	86
15						133	129	7.6			111	4.0	84	86
16						133	129	6.5			115	4.0	87	85
17						133	129	6.9			115	5.2	88	90
18						133	129	7.8			114	3.4	86	88
19						132	128	8.0			110	4.4	84	86

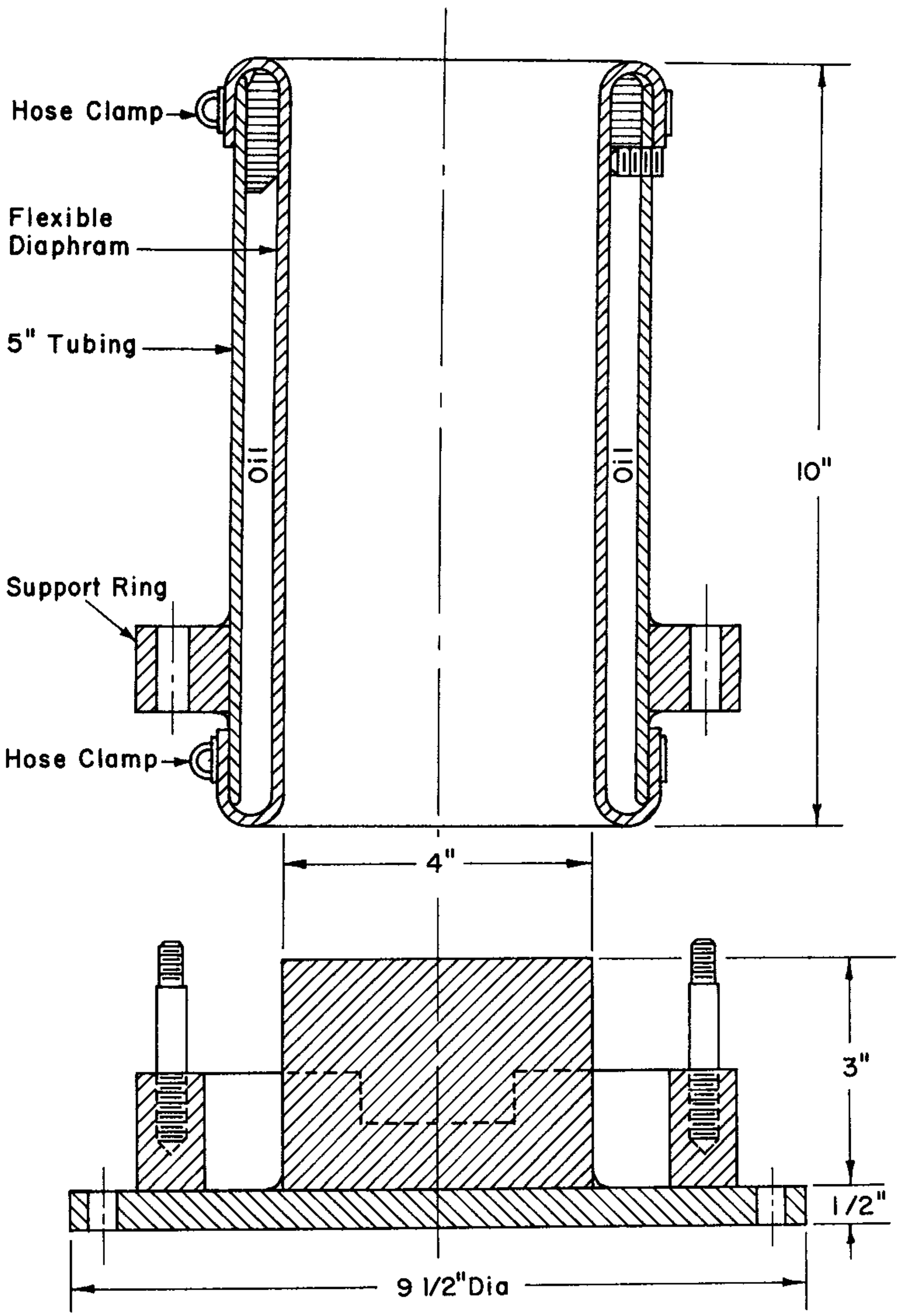
*Experimental California Soil Moisture Density Apparatus.

TABLE II - D

X-Sta-4-Cer,A,B (61-10T13C20-F)

	GRADING					FIELD RESULTS			Cal. Imp. Lab Results		Sand Vol.		R/C	
Test #	4 to 200	200 to 5 u	-5 u	PI	SE	Dry Den. Cal. Imp	Exp.* Dry Den.	Moist %	Dry Den	Moist %	Dry Den	Moist %	Field	Exp.
Column 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1						118	117	11.2			119	1.6	100	102
2	87	12	1	NP	56	118	117	7.3	117.6		118	1.2	100	101
3						123	122	9.3			120	2.0	97	98
4						128	127	9.5			125	1.8	98	99
5						130	129	10.2			129	2.2	100	100
6	35	42	13	NP	14	121	120	9.3	121.3	11.5	102	1.0	84	85
7						121	120	9.3			97	1.2	80	81
8						126	125	11.1			100	2.7	80	80
9						121	120	12.0			108	1.6	89	90
10						122	121	9.5			100	1.2	82	83
11						130	129	9.3			105	1.0	80	81
12						128	127	8.8			113	2.5	89	90
13						128	127	9.9			131	3.7	102	103
14						127	126	8.3			124	5.3	98	99
15						128	127	9.0			121	2.7	94	95
16	74	22	4	NP	33	127	126	7.4	127.8	9.1	122	2.3	96	97
17						118	117	6.8			107	0.5	92	92
18						117	116	8.6			109	3.7	93	94
19						118	117	9.2			115	0.7	98	99
20						131	130	9.1			106	0.8	81	81
21						130	129	7.8			118	1.7	91	92
22						128	127	9.4			116	2.2	90.5	91

* Experimental California Soil Moisture Density Apparatus.



FLEXIBLE WALL COMPACTION MOLD

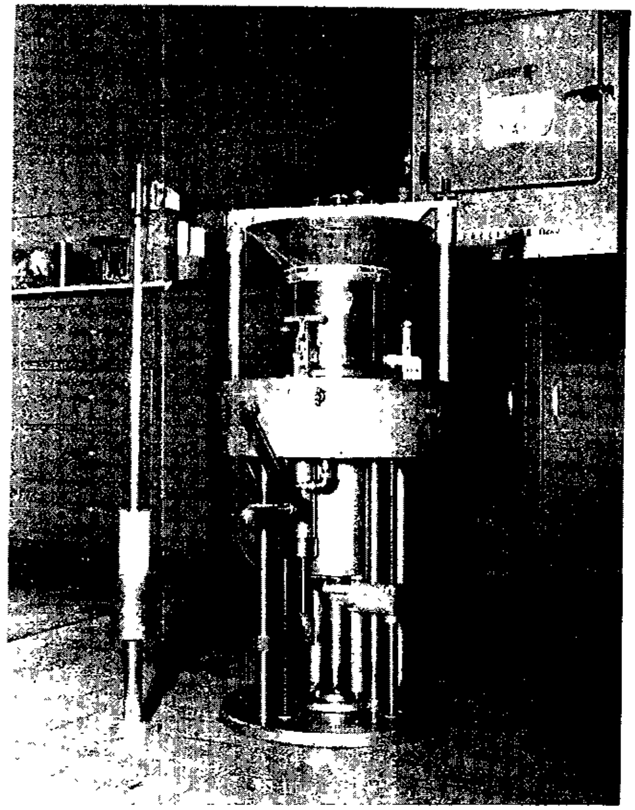


FIG. 2A Experimental Impact Apparatus # 5
California Soil Moisture-Density Apparatus

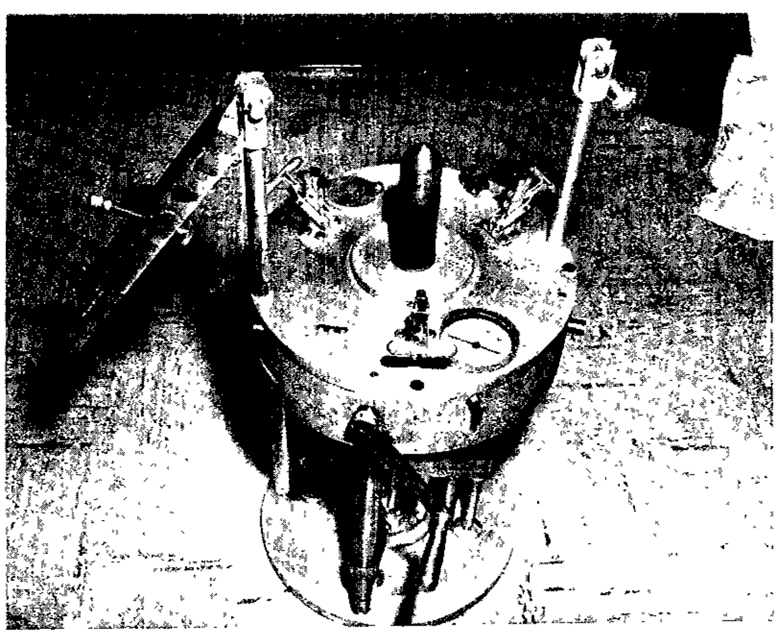
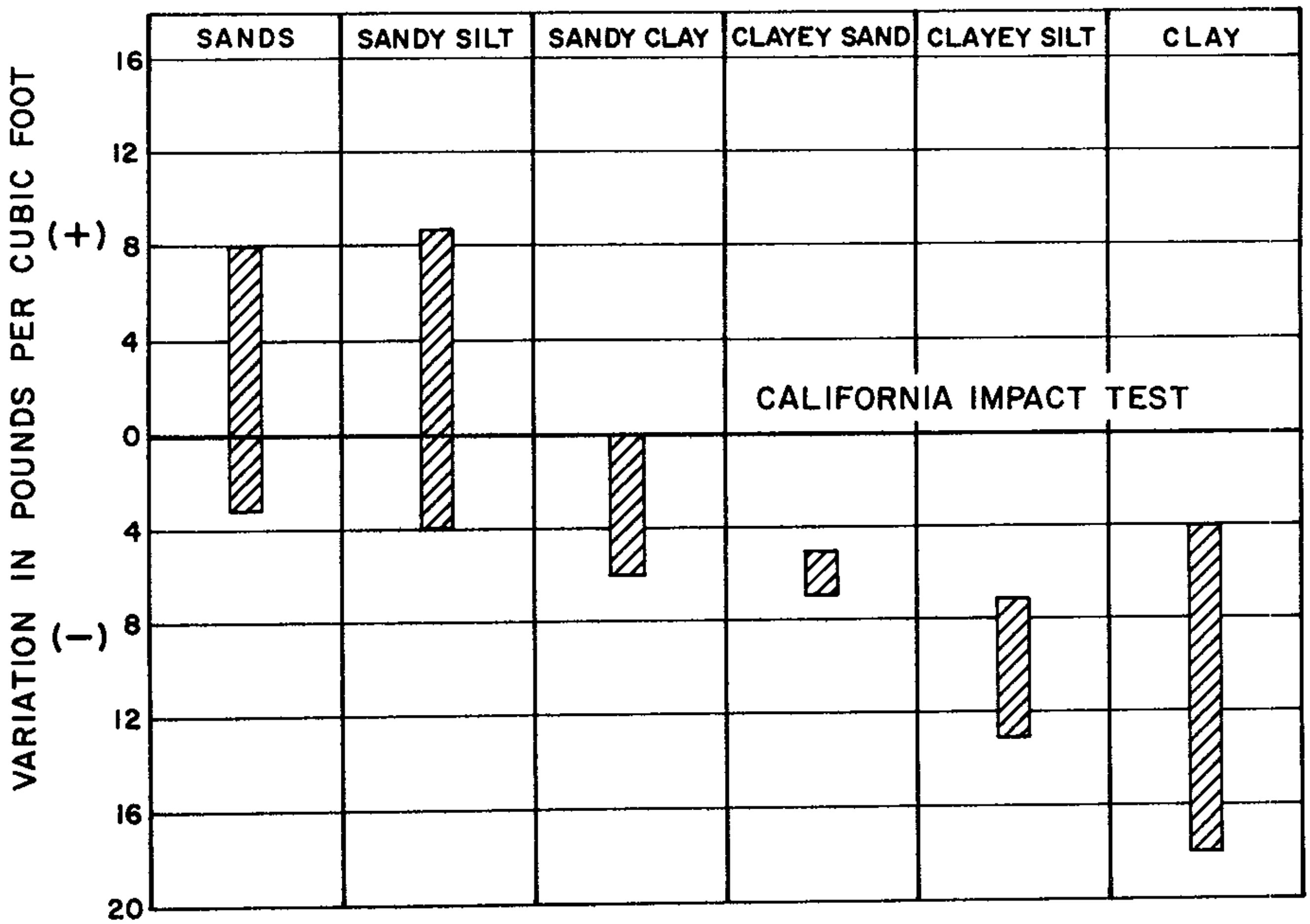
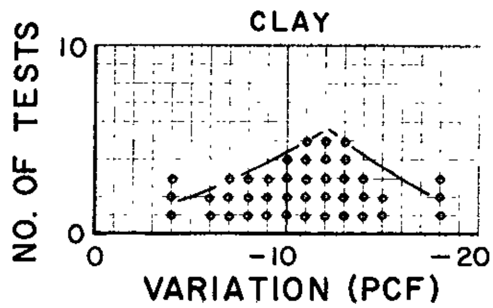


FIG. 2B Model # 5

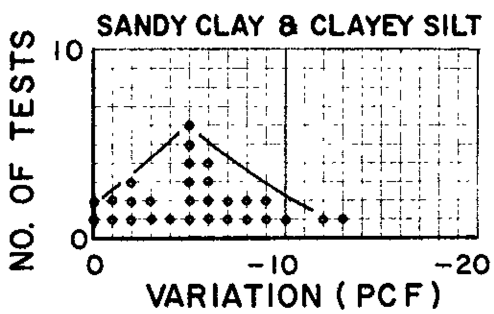
FIGURE 3


SANDS
SANDY SILT
SANDY CLAY
CLAYEY SAND
CLAYEY SILT
CLAY
VARIATION IN POUNDS PER CUBIC FOOT
(+)
(−)
16
12
8
4
0
4
8
12
16
20
CALIFORNIA IMPACT TEST

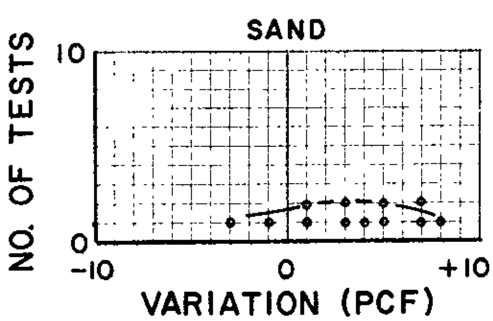
VARIATION IN DENSITY BETWEEN CALIFORNIA IMPACT TEST AND CALIFORNIA SOIL MOISTURE DENSITY TEST



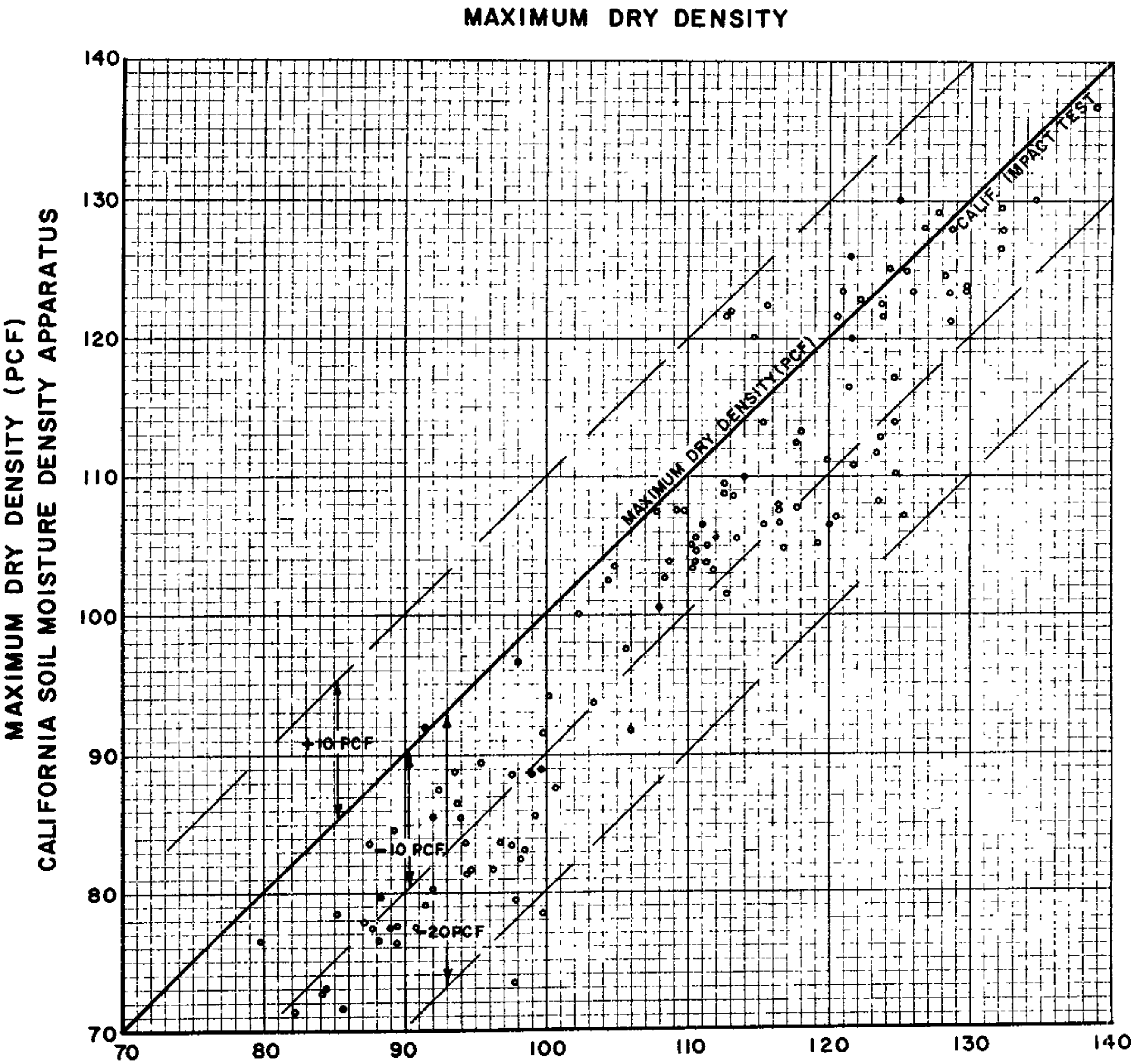
Range -4 to -18 PCF
Mean -12 PCF



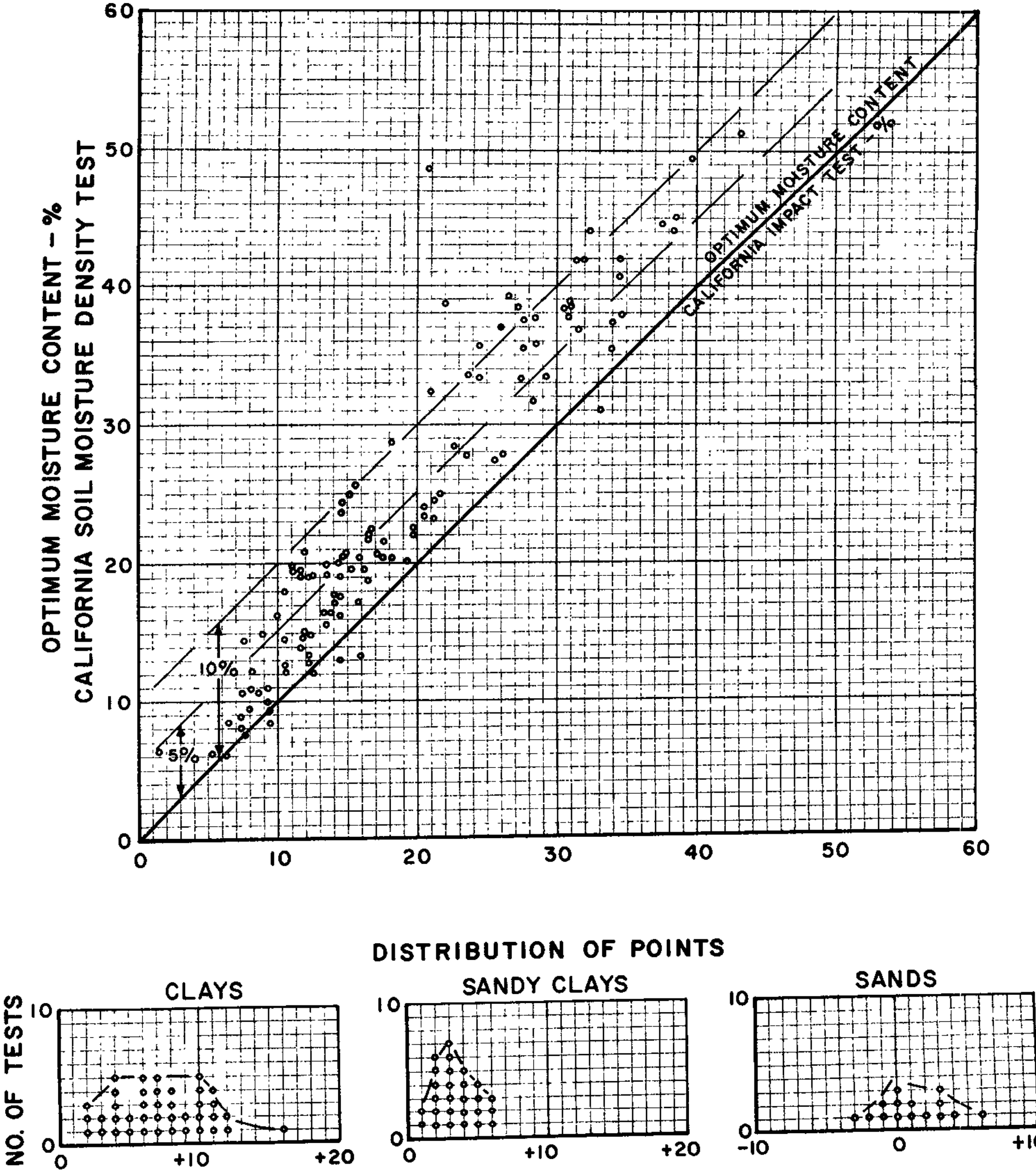
Range 0 to -13 PCF
Mean -5 PCF



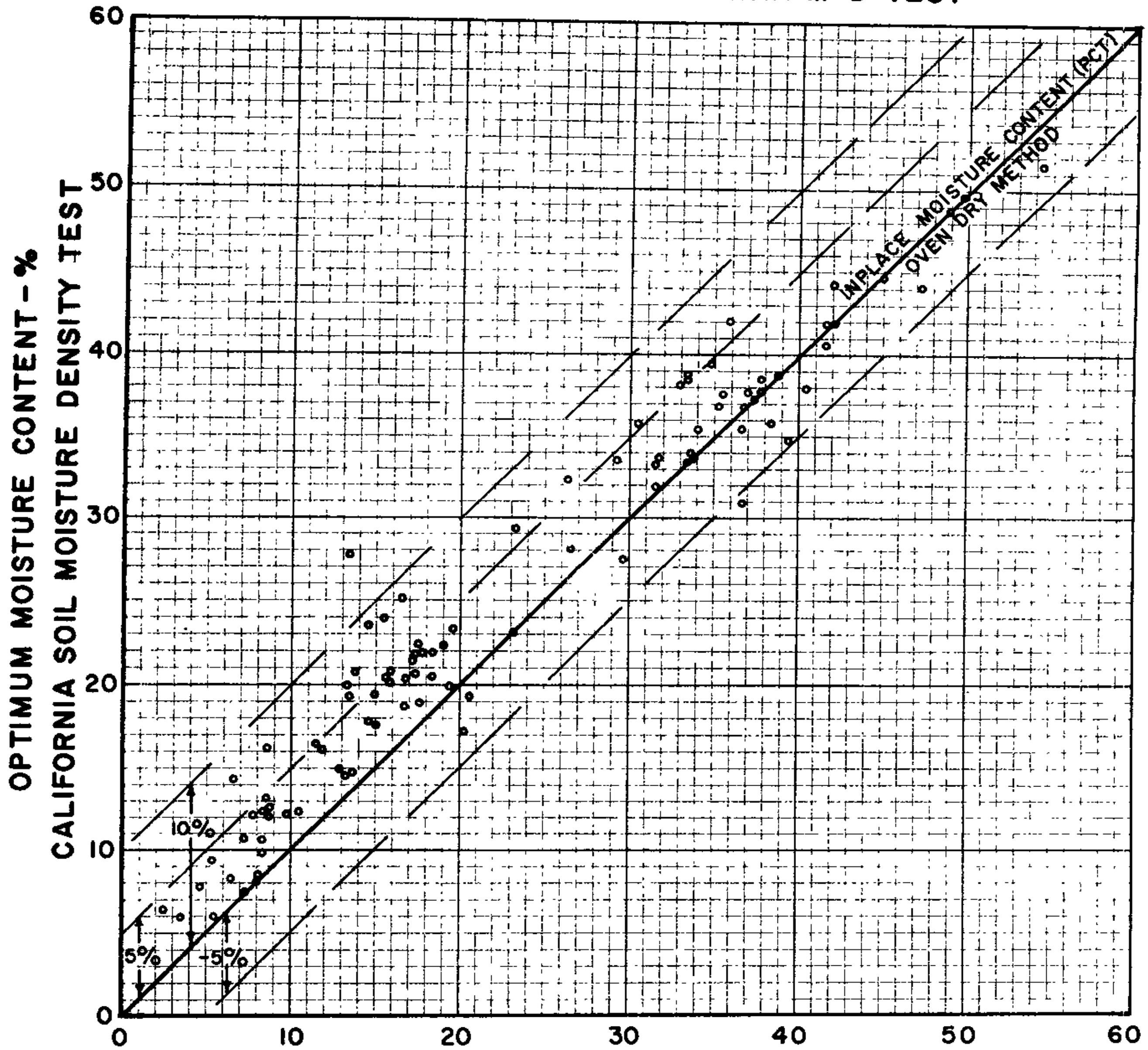
Range -3 to +8 PCF
Mean +4 PCF


MAXIMUM DRY DENSITY
MAXIMUM DRY DENSITY (PCF)
CALIFORNIA SOIL MOISTURE DENSITY APPARATUS
MAXIMUM DRY DENSITY (PCF)
CALIF. IMPACT TEST
+10 PCF
-10 PCF
-20 PCF
70
80
90
100
110
120
130
140

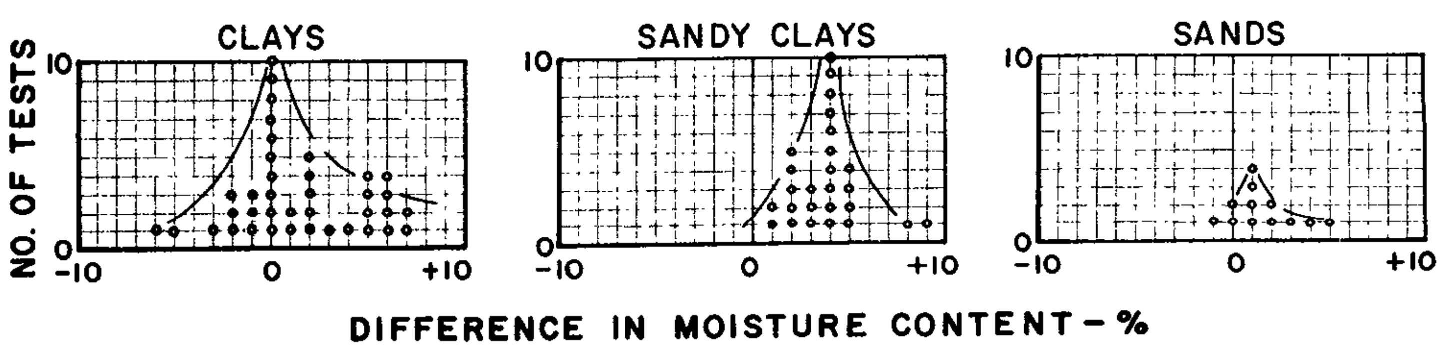
VARIATION OF OPTIMUM MOISTURE CONTENT BETWEEN CALIF. IMPACT TEST AND CALIF. MOISTURE DENSITY TEST



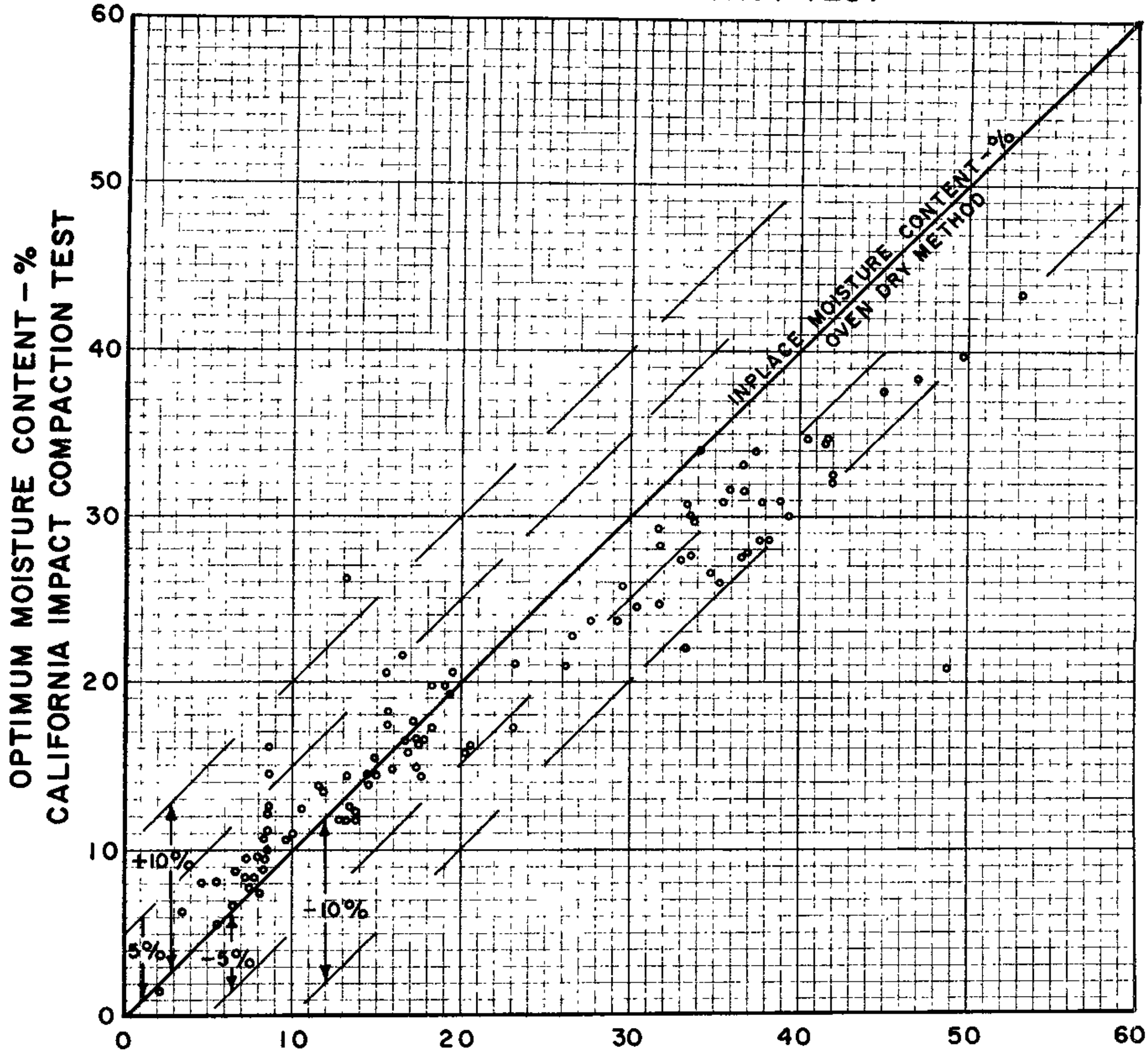
INPLACE MOISTURE CONTENT VS OPTIMUM MOISTURE CONTENT BY EXPERIMENTAL CALIFORNIA M-D TEST



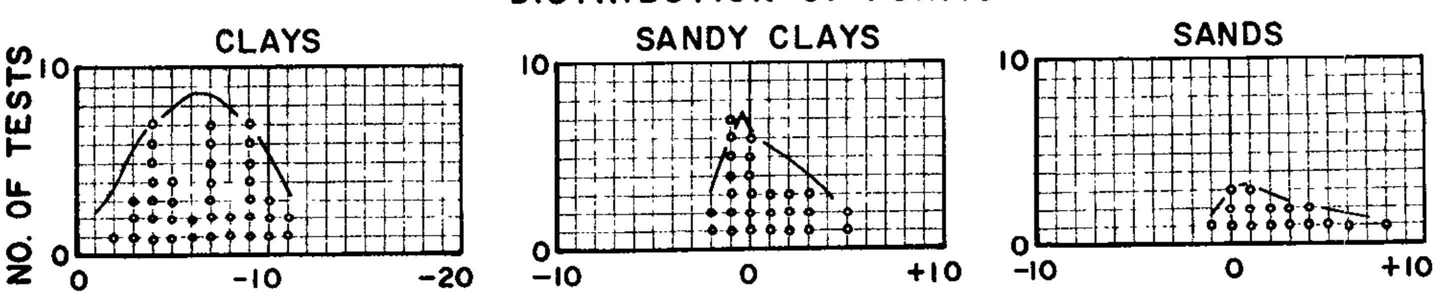
DISTRIBUTION OF POINTS



INPLACE MOISTURE CONTENT VS OPTIMUM MOISTURE CONTENT BY CALIFORNIA IMPACT TEST



DISTRIBUTION OF POINTS



DIFFERENCE IN MOISTURE CONTENT - %

PERCENT RELATIVE COMPACTION

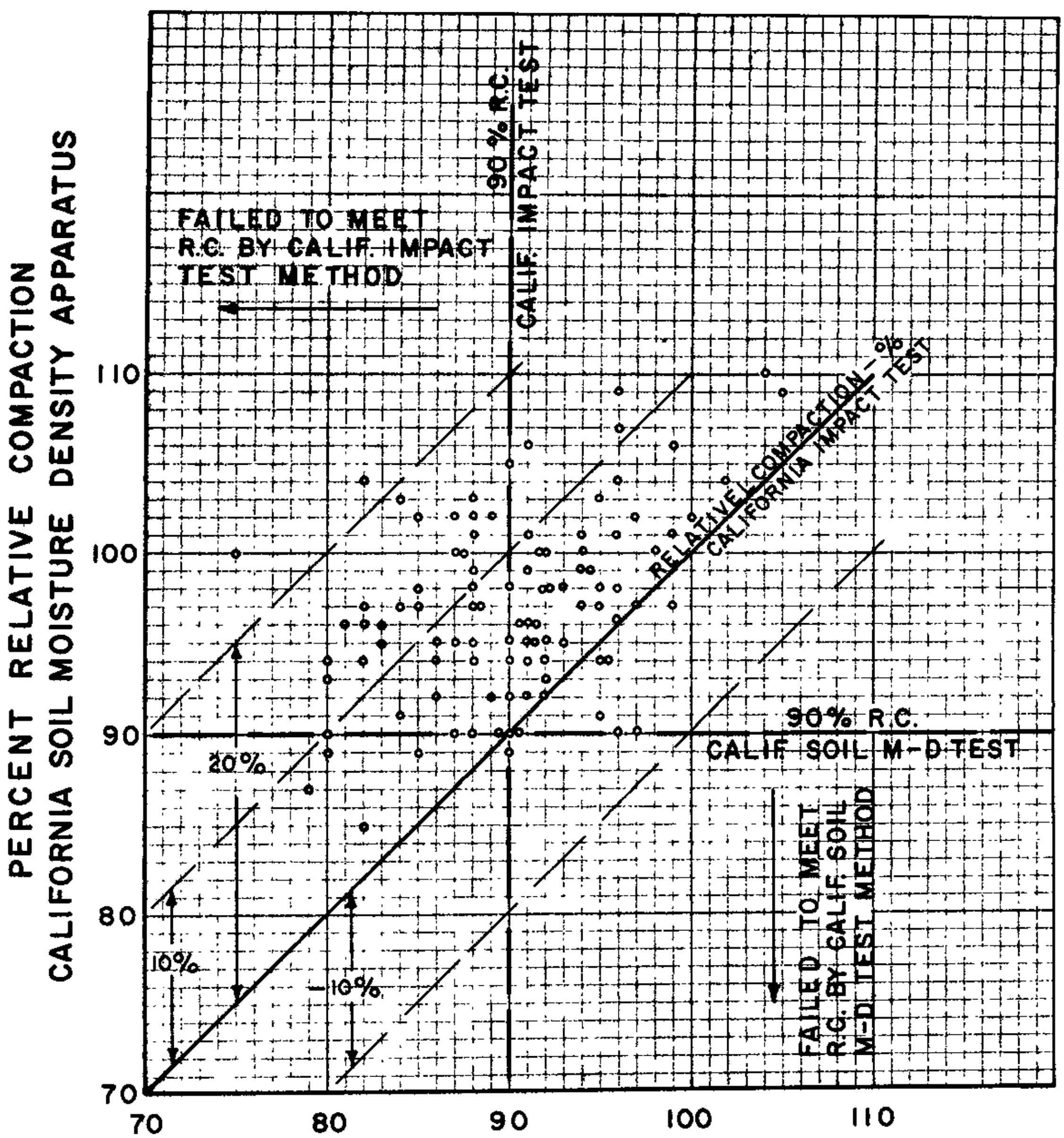


FIGURE 10

SUMMATION OF RELATIVE COMPACTION - %
CALIFORNIA IMPACT TEST VS CALIFORNIA SOIL M-D APPARATUS